

CHAMFERED FREESTANDING NITRIDE SEMICONDUCTOR WAFER AND METHOD OF CHAMFERING NITRIDE SEMICONDUCTOR WAFER

BACKGROUND OF THE INVENTION

Field of the Invention

5 This invention relates to an improvement of an edge (periphery) of a
nitride semiconductor single crystal circular wafer. The edge means a
periphery of a wafer. An as-cut wafer has a sharp edge which causes break,
crack, split, chip or scratch of the wafer. Then, the edge part is slantingly
polished into a round periphery. The slanting polishing of edges is called
10 "bevelling" or "chamfering" for discriminating the edge slanting polishing
from flat polishing of wafer surfaces. Semiconductor nitrides mean gallium
nitride (GaN), indium nitride (InN) and aluminum nitride (AlN). The
nitrides are rigid but fragile materials. Processing of semiconductor nitride
wafers is far more difficult than silicon (Si) wafers or gallium arsenide
15 (GaAs) wafers.

 This application claims the priority of Japanese Patent Application No.
2003-98979 filed on April 2, 2003 and Japanese Patent Application No.
2003-275935 filed on July 17, 2003, which are incorporated herein by
reference.

20 It has been very difficult to produce a large good semiconductor
nitride bulk single crystal wafer. Someone has recently succeeded in
producing freestanding GaN wafers on a small scale. Most of the
freestanding GaN wafers are still small rectangular plates whose side is about
10mm to 20mm. Technology of producing GaN wafers is still not fully

matured for serving GaN crystals as a substrate wafer of making InGaN type blue light lasers on a mass-production scale. Circular single crystal wafers of InN and AlN have not been yet produced except experimental trials.

At length, the production of circular GaN single crystal wafers becomes
5 feasible. An unprocessed sharp edge of an as-cut wafer causes cracks, scratches or breaks of the wafer. Peripheral parts (edges) of semiconductor wafers are used to be slantingly polished for avoiding occurrence of cracks or breaks. The process of polishing wafer peripheries into slanting edges is called "bevelling" or "chamfering". Bevelling or chamfering has been one of
10 established processes in the case of silicon wafers or gallium nitride wafers for which production technology has been fully matured. Silicon wafers are rigid, sturdy and tough. A silicon wafer is chamfered by bringing a periphery of the wafer into contact with a rotary whetstone, rotating both the whetstone and the wafer in reverse directions and polishing the periphery into
15 a slanting, round edge. Toughness of silicon enables rotary whetstones to chamfer edges of silicon wafers.

Description of Related Art

①Japanese Patent Laying Open No.9-181021, "Beveling method of wafer", proposed a method of bevelling a silicon wafer by a sophisticated diamond
20 rotary whetstone including 5wt.% to 30wt.% of ultrafine diamond particles of a diameter from 3nm to 18nm and 70wt.% to 95wt.% of small sized diamond granules of a diameter from 5 μ m(5000nm) to 8 μ m(8000nm). This is a complex rotary whetstone including two different kinds of whetting granules, one is the ultrafine particles and the other is the small particles. ① wrote
25 that the conventional rotary whetstones had been composed of gross granules

of an average diameter of 15 μ m to 30 μ m for chamfering silicon wafers and the gross granules caused breaks of wafers or cracks on wafers. For avoiding the beaks and cracks, ① proposed silicon wafer bevelling by the fine particle whetstone. Use of the ultrafine particles of a diameter of 3 nm to 18nm suppresses cracks or breaks from occurring. The small sized particles of a diameter of 5 μ m to 8 μ m were intentionally used for compensating for delay of chamfering induced by the ultrafine particles. ① was an improvement of bevelling silicon wafers by a fine particle implanted rotary whetstone for avoiding occurrence of breaks and cracks.

② Japanese Patent Laying Open No.6-315830, "Beveling method for cut-resistant material", proposed an electrolytic bevelling method for silicon wafers. ② complained that silicon wafers were too rigid and resistant to mechanically bevel and diamond whetstones should be used for silicon bevelling which raised the cost of silicon chamfering. The electrolysis method of ② supplies silicon wafers with an electrolyte, applies voltage to the silicon wafer via the electrolyte and chamfers edges of the wafers by the action of electrolysis. ① and ② are improvements of silicon wafer bevelling.

③ Japanese Patent Laying Open No. 2002-356398 (Date of publication of application: December 13, 2002), "Gallium nitride wafer", proposed an invention of bevelling of GaN wafers by the same invention as the present invention.

Current chamfering technology of the inventors of the present invention has chamfered a circular GaN wafer by making use of a rotary metal-bonded circular whetstone having implanted diamond granules of #100 mesh to #400

mesh (optimum mesh ; #200), circumscribing a circular wafer to the rotary whetstone, and rotating the rotary whetstone and the wafer in inverse directions at 800m/min to 2000m/min which is an ordinary range of rotation speed, as shown in Fig.1. A periphery 6 of the circular wafer 2 is pushed
5 to a concave rotary whetstone 3 which wears fixed diamond granules on an outer round surface. The wafer 2 is circumscribed with the rotary whetstone 3. A liquid is supplied to the rotary whetstone 3 and the wafer 2. The rotary whetstone 3 rotates at a high speed in a direction. The wafer is also rotated in an inverse direction at a low speed. The implanted granules abrade the
10 periphery of the wafer at a high rate. The circumscribing contact applies strong shocks upon the edge of the wafer. It takes about ten minutes to twenty minutes to eliminate a diametrical 1mm wide margin. It is rapid bevelling. A final shape of the edges is determined in accordance with the standard of the SEMI (Semiconductor Equipment and Materials International).

15 Fig.5 depicts sizes of parts of a 2-inch GaN wafer in the chamfering steps. A necessary bevelling margin is a radial 1mm width. An initial wafer has a 52 mm diameter and a 520 μ m thickness. Before chamfering, an orientation flat OF and an identification flat IF are formed at peripheral portions by a dicer or a grinding whetstone for signifying crystallographical
20 orientations. A final length of the OF should be 16mm. A length of the IF should be 7mm. The OF line should be cut along a line distanced by 2.32mm from a point on the circumference. The OF is usually a cleavage plane {1-100}. The IF line should be cut along another line distanced by 1.25mm at another point on the circumference. The IF is vertical to the OF.
25 Relative positions of the OF and the IF are determined for clockwise aligning

in the order when a facing surface is a top surface. Sizes of parts are predetermined as such.

Prior edge processing of the inventors of the present invention chamfers, for example, a 52mm ϕ GaN wafer having OF and IF by
5 circumscribing the wafer with a metal-bonded diamond rotating whetstone, rotating the diamond whetstone, grinding a circumference of the wafer till the outer diameter of the GaN wafer is reduced to 50mm ϕ , as shown in Fig.1. The diameter should be reduced by 2mm. The periphery which is eliminated away is called a polishing margin. The polishing margin is 1mm in radius or
10 identically 2mm in diameter. Hard diamond fixed granules have a strong force of abrading rugged wafer edges. Such bevelling for the diametrical 2mm margin takes only about 20 minutes to 40 minutes. The processing time is short enough. The processing improves roughness of the wafer down to about Ra10000nm to Ra6000nm (Ra10 μ m to Ra6 μ m) in the best case.
15 However, the yield of chamfering is low. Sometimes the periphery is scratched or chipped in the chamfering step. Sometimes the wafer cracks or breaks. Impulsive contact with the hard rotary whetstone is often destructive for the wafer. Ra6 μ m is the lowest limit in the circumscribing rotary contact whetstone. It is desired to reduce the roughness less than
20 Ra5 μ m. But, such smoothness less than Ra5 μ m is beyond the power of the metal-bonded circumscribing rotary whetstone rotating at an ordinary speed. It may supposed that a very slow rotation whetstone will be able to bevel the fragile GaN wafer without scratching, chipping or cracking. A ten-hour whetting making use of the same metal-bonded diamond rotary whetstone
25 succeeded in chamfering a circumference to roughness of about Ra3 μ m.

However, the slow whetting has drawbacks of excess dissipation of whetstones, jamming of meshes with dust and big fluctuation of final properties of the wafer. The long-time whetting is not practical for giving mirror smoothness to GaN wafers.

5 Whetting powder of #200 is far coarser powder than the whetting powder for polishing the silicon wafers described in the previously cited ① Japanese Patent Laying Open No.9-181021, "Beveling method of wafer". Thus, a wafer polished by the #200 powder has a rough surface of $Ra10\mu m$ to $Ra6\mu m$.

10 The inventors had employed the coarse whetting powder for bevelling GaN wafers. GaN wafers are rigid but fragile. The rigidity forced the inventors to employ the coarse powder. It is, however, difficult to finish GaN wafers due to the fragility. If a GaN wafer is in outer-contact with a rotating whetstone and the edge is bevelled by the rotating whetstone, the
15 edge or the whole of the wafer breaks during the bevelling process with high frequency. Even if the edges are not broken, the chamfered edges suffers from high roughness of $Ra=10\mu m$ to $6\mu m$ as described before.

 It may be perhaps effective to use rotating whetstones of fine granules of smaller diameters for reducing the occurrence of scratches. However,
20 employment of smaller-sized whetting granules requires longer time for polishing edges of wafers, which raises cost of edge polishing. Use of the fine granule whetstones has other drawbacks of raising the probability of cramming meshes with whetting wastes and shortening the lifetime of whetstones.

25 One purpose of the present invention is to provide a freestanding

gallium nitride wafer which is free from occurrence of cracks from peripheral parts (edges).

Another purpose of the present invention is to provide a freestanding gallium nitride (GaN) wafer which is free from occurrence of scratches or
5 breaks from edges.

Another purpose of the present invention is to provide a freestanding gallium nitride (GaN) wafer with clean edges which do not invite particle adhesion or waste contamination. A further purpose of the present invention is to provide a method of chamfering an edge of a nitride wafer without
10 incurring scratching, splitting or breaking of the wafer. A further purpose of the present invention is to provide a method of chamfering an edge of a nitride wafer without clogging of meshes with whetting materials. This invention is also applicable to other nitride semiconductor wafers of aluminum nitride (AlN) or indium nitride (InN) besides GaN.

15 SUMMARY OF THE INVENTION

The present invention proposes a nitride semiconductor wafer having an edge bevelled to roughness Ra smaller than $Ra5\mu m$ but larger than $Ra10nm$ ($10nm \leq Ra \leq 5\mu m$). The roughness less than $Ra5\mu m$ enables the nitride wafer to reduce a crack occurrence rate under 50%.

20 More favorably, the present invention proposes a nitride semiconductor wafer with a smooth edge bevelled to roughness Ra smaller than $Ra1\mu m$ but larger than $Ra10nm$ ($10nm \leq Ra \leq 1\mu m$). The edge roughness less than $Ra1\mu m$ allows the wafer to decrease a crack occurrence rate under 10 %.

Furthermore, the present invention proposes a edge roughness less than
25 $Ra0.1\mu m$ for a nitride semiconductor wafer. The small roughness less than

Ra0.1 μ m can suppress a crack occurrence rate under 6 %.

In any cases, the lowest limit of roughness is Ra10nm. Ra10nm is the limit restricted by the method of the present invention relying upon whettapes. Ra10nm is equal to a value in a scope of minute flat surface polishing. The edges need not have extremely high flatness equivalent to the flatness of surfaces.

Thus, the present invention proposes a nitride wafer having edge roughness of,

- (1) Ra5 μ m \sim Ra10nm,
- 10 (2) Ra1 μ m \sim Ra10nm or
- (3) Ra0.1 μ m \sim Ra10nm.

Fig.6 shows a section of a GaN wafer having an edge which is bevelled by an apparatus of the present invention. The edge is polished into a round shape. The polished edge can have flat portions instead of the round portions. Polishing of the edge portion is done by a whetting material which has a flexible body and continuously supply a cutting edge to an object wafer, for example, a whettape. The tape-polishing can realize a natural round shape of the edges.

Smoothing the edge of wafers reduces an occurrence rate of cracks and enhances yield of producing good wafers. The smooth edges also decrease the probability of breaks and cracks on wafer processes.

Rotation whetstones, however, are not suitable for polishing edges of GaN wafers, because GaN is fragile. The present invention employs whettapes instead of the rigid rotation whetstones. Whettapes mean a continual coiled tape paper or cloth implanted with polishing granules 5.

Fig.2 and Fig.3 show a polishing process by bringing an edge 6 of a wafer 2 into contact with a whettape 4, rotating the wafer 2 and polishing the edge 6 of the wafer 2. The whettape 4 is soft enough to bend into arbitrary curvatures, because a base is paper or cloth which is rich in elasticity.

5 Besides, a contacting area between a wafer and a whetting material differs. A conventional rotating whetstone is in outer-contact with an edge of an object wafer. The contact is a spot contact in the conventional wafer/whetstone. An effective area of the contact is very narrow. The contacting pressure per unit area is quite strong. The strong pressure is apt
10 to break wafers in the conventional rotating whetting.

The whettape shown in Fig. 3, however, has a larger effective contacting area indicated by points EFG with the wafer, because the whettape flexibly bends along the wafer. As shown in Fig. 3, the wafer 2 is inscribed in the whettape 4 at the points E, F and G. Since the whettape 4 has
15 elasticity, a central angle EOG of the wafer 2, which shows a contacting area between the wafer and the whettape, can be 40 degrees to 90 degrees. The contacting area is wide along a circumference of the wafer as illustrated in Fig. 3 and is also wide along a thickness of the wafer as shown in Fig. 2. Therefore, since the contacting area is wide in the case of the whettape, a
20 contacting pressure per unit area can be far smaller than that of the conventional whetstone. Probability of occurrence of breaks of wafers in process can be effectively suppressed.

Probability of occurrence of clogging is higher in finer whetstones than in grosser whetstones in the case of rotary whetstones. Unlike the rotary
25 whetstones, the whettapes always renew whetting granules 5 implanted on a

continual cloth tape at a feeding speed U . The continual renewal of acting granules prevents whetdust from remaining and from jamming into gaps of granules. Due to the continual replacement of granules, the whettape is immune from the occurrence of clogging of whetdust. Suppression of clogging enables the whettape to make use of far finer granules than the ordinary rotary whetstone.

Advantages of the present invention are described. The invention proposes a freestanding nitride wafer having an edge of high smoothness of $Ra10nm$ to $Ra5\mu m$ and a method of chamfering a circular freestanding nitride wafer by a whettape having implanted granules. The whettape is rich in elasticity, softness, shock-absorption and toughness. The whettape inscribes an edge of a wafer, which increases a contact length and reduces the force per unit area. Such features of the whettape reduce the probability of splitting, scratching or breaking in chamfering steps and enhance the final obtainable edge smoothness to $Ra10nm$ to $Ra100nm$. Feeding of the whettape renews contacting granules and prevents the fixed granules from being jammed with waste.

Prior bevelling by the rotary whetstones can chamfer the edges of circular wafers to $Ra10\mu m$ to $Ra6\mu m$ at best. It is impossible to obtain smoothness under $Ra6\mu m$ by the prior rotary whetstone method. As shown in Fig.4, the roughness of $Ra10\mu m$ to $Ra6\mu m$ incurs over 60% of a crack occurrence rate. An upbeat of edge smoothness enables the present invention to reduce the probability of occurrence of cracks and raise the yield of bevelling. Fig. 4 indicates $Ra5\mu m$, which corresponds to the upper limit of the present invention and invites cracks at a 50% rate. This invention can

produce good wafers with a crack occurrence rate less than 50%.

Preferable smoothness is $Ra1\mu m$ to $Ra10nm$. The roughness under $Ra1\mu m$ ensures the present invention to reduce the crack occurrence rate to less than 10%.

5 Further favorable smoothness is $Ra0.1\mu m$ to $Ra10nm$. The roughness under $Ra100nm$ decreases the crack occurrence probability under 6%.

In addition to the cracks, the present invention can decrease the probability of breaks, splits, crashes and contamination by waste, dust or foreign materials in wafer processes and in conveying processes through the enhanced smoothness of wafer edges. GaN, AlN and InN freestanding wafers of high quality are obtained by the present invention.

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BRIEF DESCRIPTION OF THE DRAWINGS

Fig.1 is a sectional view of a spool-shaped rotating whetstone with an inner curved polishing surface for bevelling edges of a wafer for illustrating a conventional wafer bevelling method.

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Fig.2 is a vertically sectioned view of a part of a freestanding GaN wafer and an elastic whettape being in contact with an edge of the GaN wafer and running in an angular direction around the edge for showing a wafer bevelling method of the present invention.

20 Fig.3 is a horizontally sectioned view of a part of the freestanding GaN wafer and the elastic whettape being in contact with the edge of the GaN wafer and running in an angular direction around the edge for showing a wafer bevelling method of the present invention.

Fig.4 is a graph for showing a relation between a surface roughness Ra (μm) of edges of GaN wafers and an occurrence rate (%) of cracks. The

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abscissa is the surface roughness Ra (μm) of edges. The ordinate is the crack occurrence rate (%).

Fig.5 is a graph showing sizes of an original free-standing 2-inch ϕ GaN wafer which has a 52mm diameter and a 520 μm thickness, and a
5 processed wafer having an orientation flat (OF), an identification flat (IF) made on edges of the wafer by edge grinding and an edge which is polished and reduced by 2mm diameter (1mm radius) by a whettape in accordance with the teaching of the present invention.

Fig.6 is a sectional view of a GaN wafer which has an edge polished by
10 a whettape into a predetermined surface roughness.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention proposes a chamfering method of bringing an edge of a circular nitride wafer to a whettape, rotating the nitride wafer in contact with the whettape, feeding the whettape and polishing the edge of the
15 wafer to roughness Ra between Ra5000nm and Ra10nm, more favorable roughness between Ra1000nm and 10nm and the best case roughness between Ra100nm and Ra10nm. This invention further proposes a nitride wafer having a chamfered edge of roughness Ra of

- (1) Ra5000nm to Ra10nm,
- 20 more favorable edge roughness of
- (2) Ra1000nm to Ra10nm,
- and the best edge roughness of
- (3) Ra100nm to Ra10nm.

The whettape method of the present invention polishes a periphery of a
25 GaN (or InN or AlN) wafer by bringing an edge of the wafer in contact with a

whettape having implanted granules, rotating the GaN wafer in the enclosing whettape and feeding the whettape at a slow speed. Unlike the rotating whetstone, the whettape polishing of the present invention rotates the wafer. The powder granules are implanted on a soft, elastic cloth or paper. The whettape can be made of cloths, polyurethane, leather, rubber or paper. Elastic and soft contact with the whettape absorbs shocks and alleviates the force acting upon the wafer from a whetting machine. The whetting granules are, for example, silicon carbide (SiC), alumina (Al_2O_3), diamond (C) or silica.

And, a liquid for whetting can be also used with the granules and the liquid includes silicon carbide (SiC), alumina (Al_2O_3), diamond (C) or colloidal silica. The tape for whetting is made of cloths, polyurethane, leather, rubber, or paper. Since the whettape is in inscribing contact with the edge, a contacting region is still wider than the case of the ordinary rotary whetstone which circumscribes a wafer. The wide contact area can reduce pressure (force per unit area) acting between the whetting matter and the wafer. The favorable pressure is $1\text{kg}/\text{cm}^2$ to $10\text{kg}/\text{cm}^2$. Continual renewal (feeding) of the whettape inhibits the mesh from jamming with dust. Soft touch of powder, the shock-absorbing tape, the inscribing contact, slow rotation and long time processing can afford to give edges of wafers mirror-smoothness without incurring splits, scratches, breaks and cracks.

Adjustable variables are sizes (average diameter or mesh number #) of granules implanted upon the whettape, a contacting force F between the whettape and wafer edge, a line velocity V (angular velocity \times radius), a polishing time H , a tape feeding speed U and an abrasive liquid. A

single-step polishing, a two-step polishing, a three-step polishing and an over-three step polishing are available for the whettape method. In the case of multiple-steps, tapes having larger granules are followed by tapes having smaller granules. A larger mesh number (#) means a smaller average
5 diameter of granules.

Mesh sizes of granules applied to a pertinent whettape should be #300 to #5000, more favorably, #500 to #3000. Suitable feeding speeds of the whettape which depend upon granule mesh sizes are 5mm/min to 60mm/min, more favorably, 10mm/min to 30mm/min. A whettape implanted with larger
10 granules is more powerful to abrade edges but is unable to produce high-smoothness of the edge. Another whettape implanted with smaller granules is more subject to suffer from abrasion wearing, which should require higher speed of feeding. A single step of a single whettape is available. A plurality of steps with different mesh whettapes are also
15 effective. For example, a first step employs a whettape of #300 to #1000, a second step employs another whettape of #1000 to #2500 and a third step employs another whettape of #2500 to #5000. Unlike the ordinary rotary whetstones, current whetting portions of the tape can be continually renewed with the feeding of the whetting tape. The continuous renewal of whetting
20 cloth parts prevents implanted small granules from jamming with waste and maintains good polishing performance.

Since the tapewhetting is substantially a kind of mechanical polishing, a suitable polishing liquid is, for example, powder including water, powderless water, powder including oil and powderless oil. The polishing
25 liquid has functions of cooling the contacting portions, reducing abrasion

resistance, alleviating shocks acting upon edges of the object wafer and raising yield of chamfering. Necessary polishing time depends upon sizes of granules implanted on the tape. Gross-chamfering making use of larger granule tapes consumes short time. Minute chamfering processed by smaller
5 granule tapes requires long time.

The processing time H varies at the steps of chamfering. Each step requires one hour to ten hours. The smaller the granules are, the longer time the bevelling step requires. The present invention has a drawback of requiring longer processing time than the conventional rotary whetstones
10 which take only twenty minutes to forty minutes. The time-consuming drawback of the present invention can be compensated by an improvement of roughness R_a of edges of wafers.

About seven hour polishing reduces the wafer diameter by about 2mm. About 13 m of a whettape is consumed for edge-polishing of one wafer at the
15 polishing rate. Neither cracks nor splits occur. Final roughness of the edges is R_{a10nm} to $R_{a5\mu m}$. More favorable cases obtain final roughness between R_{a10nm} and $R_{a1\mu m}$. The most favorable case enjoys final roughness between R_{a10nm} and R_{a100nm} . The length of whettape per wafer would be able to be decreased down to about 10m. This invention can be
20 applied to other nitride semiconductor wafers, aluminum nitride (AlN) wafers and indium nitride (InN) wafers.

[EMBODIMENT]

A starting wafer is an as-grown GaN wafer of a 52mm diameter and a 520 μm thickness. An orientation flat (OF, 16mm of a final length) and an
25 identification flat (IF, 7mm of a final length) are formed on sides of the GaN

wafer by, for example, a dicer. Fig.5 shows a plan view of the object GaN wafer for showing sizes of the wafer. A 52mm ϕ outer full circle denotes an original size of the object wafer before edge-polishing. A left straight line shows a cutting line for the IF formation. A bottom straight line denotes a cutting line for the OF formation. A 1mm wide edge part is eliminated by the edge polishing. A 50mm ϕ inner circle shows the edge-polished wafer. Since a 1mm wide peripheral circular part is eliminated, the lengths of the left IF line and the bottom OF line are reduced to the predetermined lengths of 7mm and 16mm.

The original 52mm ϕ wafer is fixed to a chuck of a rotor by aligning centers. At a first bevelling step, an endless gross whettape of #800 mesh is used for bevelling an edge of the GaN wafer. The edge of the wafer is brought into contact with the whettape with a pressure of 7kg/cm². The wafer is rotated at a suitable speed in the state of contact with the whettape. The whettape is fed at a feeding speed of U=10mm/min. Water is supplied as a coolant to the polished wafer and the whettape. The wafer edge is chamfered for two hours by the #800 mesh whettape. The roughness is measured by an AFM (atomic force microscope). The first chamfering step using the #800 mesh whettape reduces roughness of the edge to Ra0.9 μ m (= Ra900nm).

At a second step, another middle whettape of #2000 mesh is utilized. The gross-polished edge of the wafer is further chamfered by the #2000 mesh whettape at a 20mm/min feeding speed (U=20mm/min) with a pertinent pressure. Five-hour bevelling gives the edge a roughness of Ra0.3 μ m (= Ra300nm) by measurement on the AFM.

At a third step, a fine whettape of #3000 mesh is further utilized. The wafer edge is further bevelled for 6.5 hours by the whettape which is fed at a feeding speed of $U=30\text{mm/min}$. The roughness of the edge is reduced down to $Ra0.1\mu\text{m} = Ra100\text{nm}$ by the AFM measurement. A series of the three
5 chamfering steps by the whettapes succeeded in obtaining a smooth edge of roughness $Ra0.1\mu\text{m}$.

As described before, the first purpose of the present invention is to suppress the roughness of edges of GaN wafers or other nitride wafers under $Ra5\mu\text{m}$ ($Ra\leq 5\mu\text{m}$). Such roughness has been accomplished by the first step
10 ($Ra0.9\mu\text{m}$ by the whettape of #800 mesh) of bevelling of the embodiment. As clarified in Fig. 4, $Ra1\mu\text{m}$ corresponds to 10 % of the crack occurrence rate. It is significant to suppress the edge roughness under $Ra1\mu\text{m}$ for the sake of preventing cracks from occurring. It is possible to stop the bevelling at the first step which brings about the edge roughness $Ra0.9\mu\text{m}$.

15 The second bevelling step heightens smoothness of the edge of the GaN wafer up to $Ra300\text{nm}$ by a finer whettape of #2000. The second step can accomplish the smoothness of the range (2) ($Ra1000\text{nm}$ to $Ra10\text{nm}$) above-cited. It is also possible to finish the chamfer at the second step.

The third bevelling step of the embodiment enhances smoothness of the
20 edge up to $Ra100\text{nm}$ by the finest whettape of #3000. The third step chamfer can produce excellent smoothness of the edge, which suppresses a crack occurrence rate to 5% to 8%, as exhibited in Fig.4. There are other factors inducing cracks. Such reduction of the crack occurrence probability is a remarkable effect of the slow tape-bevelling of the present invention.